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(54) Abstract Title
Flow control apparatus and method

(57) A method for obtaining equalized production from deviated wellbores comprising a plurality of spaced apart flow control device 20a-n which are deployed along the length of the wellbore 14. Each control device includes a flow valve 24a-n and control units 26a-n to control flow output from the flow control device. The control unit may communicate with surface equipment 50 or act autonomously to take actions downhole based on programmed instructions provided to the control unit. The fluid from various zones Z_1-Z_n are drawn in a manner that depletes the reservoir uniformly along the entire length of the wellbore. Each flow control device is initially set at a rate determined from initial reservoir simulations or models. The depletion rate, water, oil and gas content, pressure, temperature and other desired parameters are determined over a time period. This data is utilised to update the initial reservoir model, which in turn is utilised to adjust the flow rate from one or more zones so as to equalize the flow rate from the reservoir. The present invention also provides a flow control device which includes an outer shroud (fig2B,235) that reduces the effect of fluid impact on the flow control device and one or more tortuous paths (fig2A,214) which carry the formation fluid into the production tubing (fig2A,220).

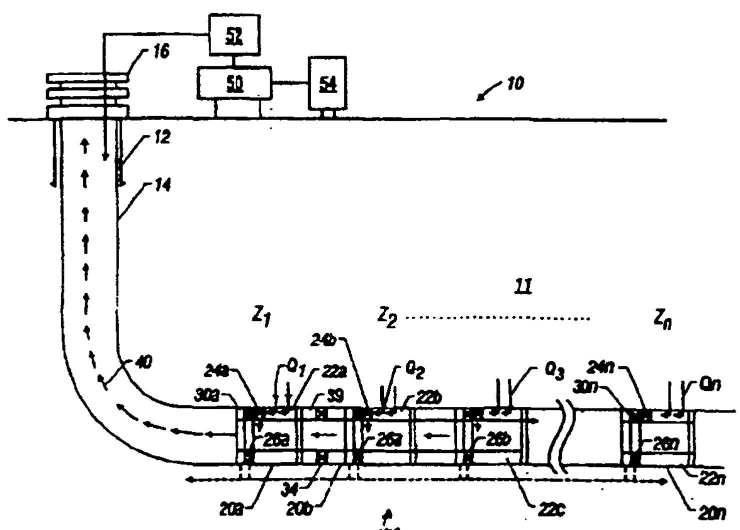

Figure 1

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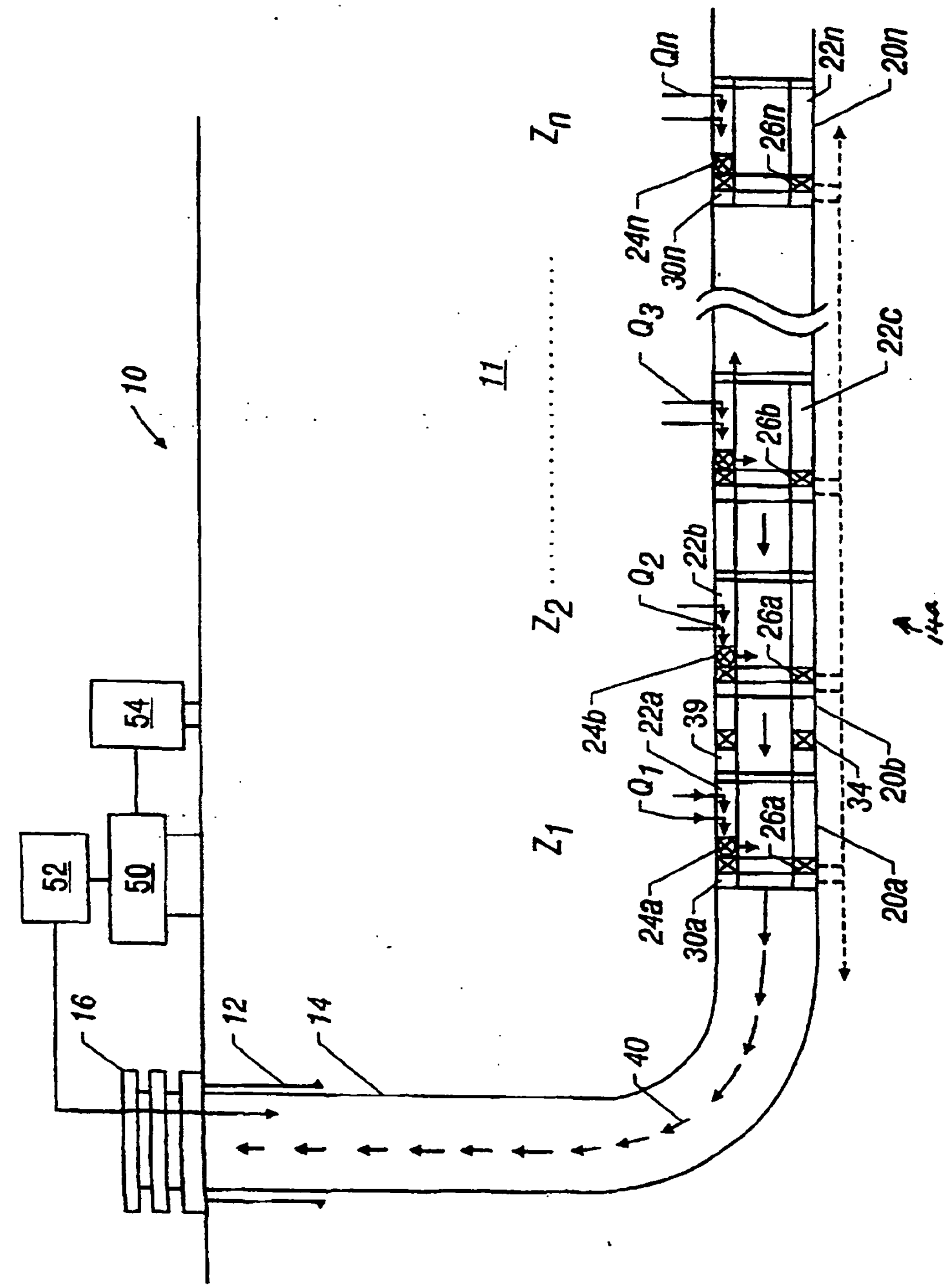
10
11
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20a
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26a
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26b
26n
30a
30n
34
39
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52
54
Q_1
Q_2
Q_3
Qn
Z_1
Z_2
Z_n

Figure 1

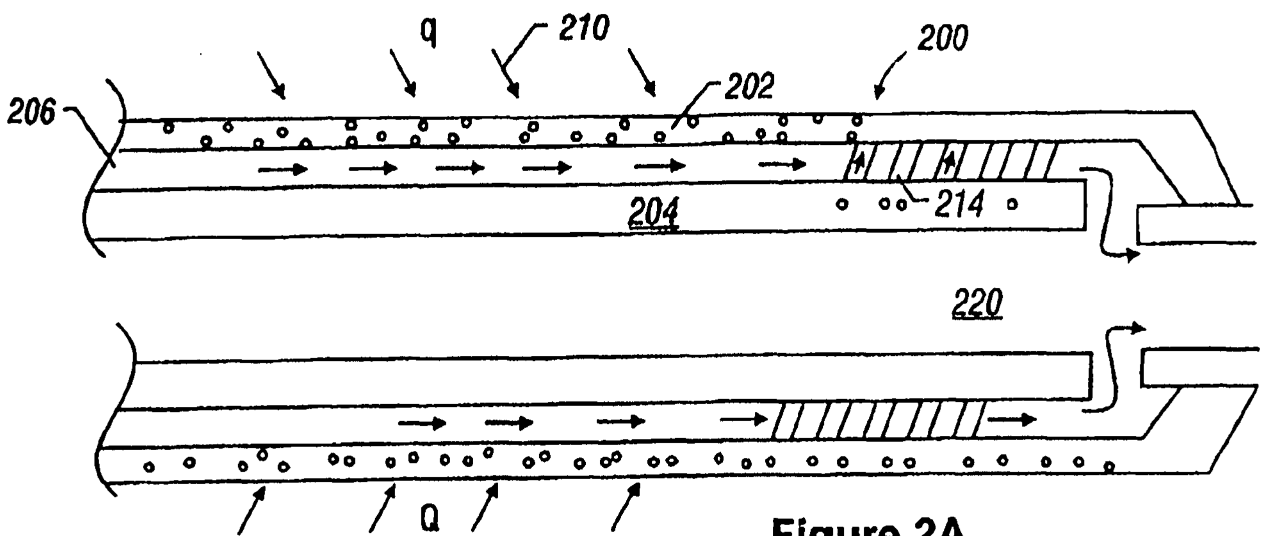


Figure 2A

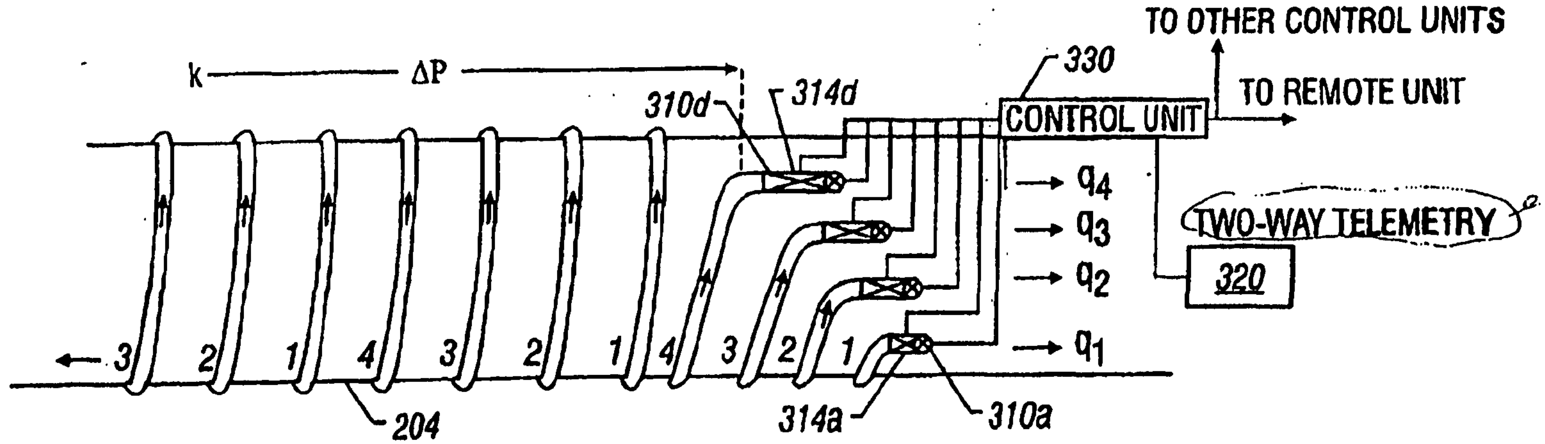
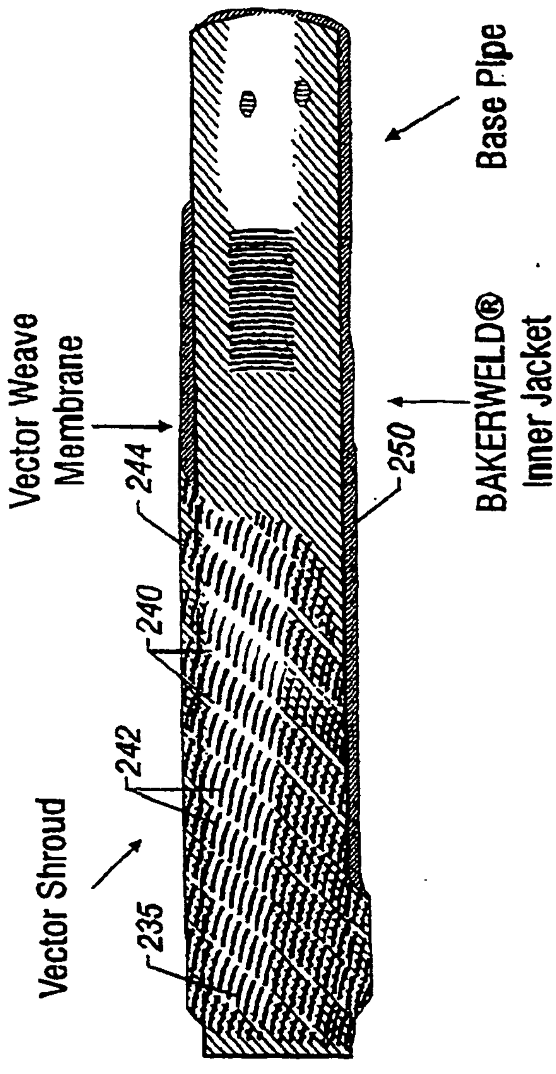


Figure 3



Base Pipe
Vector Weave
Membrane
BAKERWELD®
Inner Jacket
244
250
240
242
Vector Shroud
235

Figure 2B

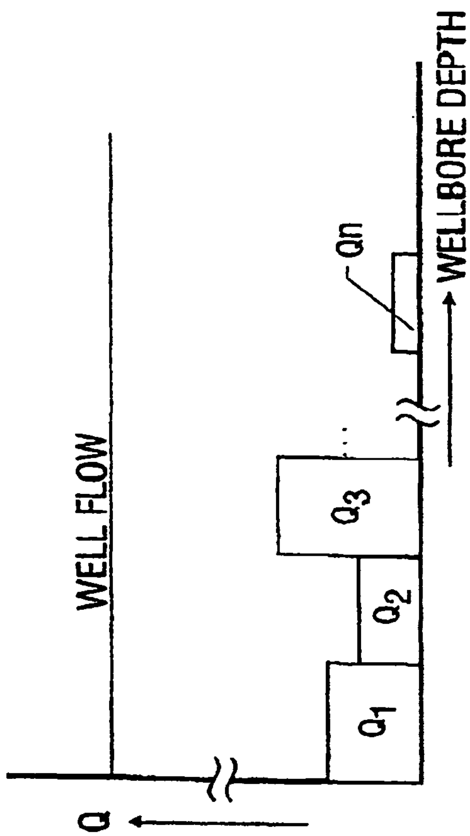


Figure 4

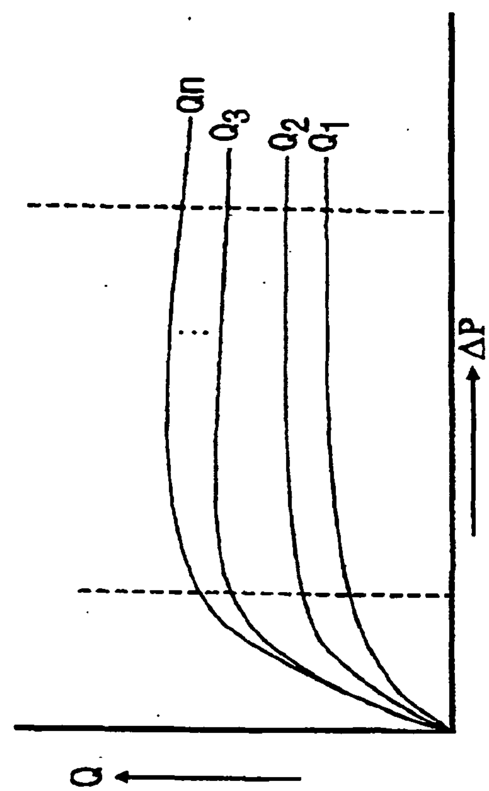


Figure 5

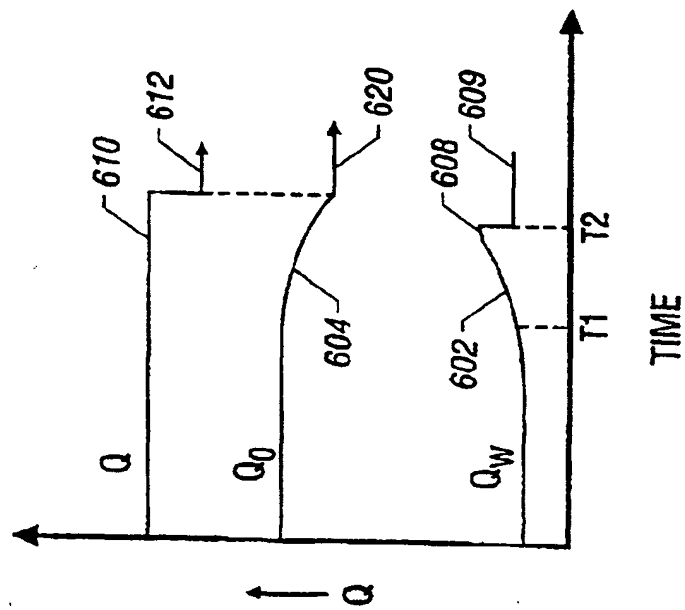


Figure 6

Horizontal Well with Permeabilty Contrasts and Shale

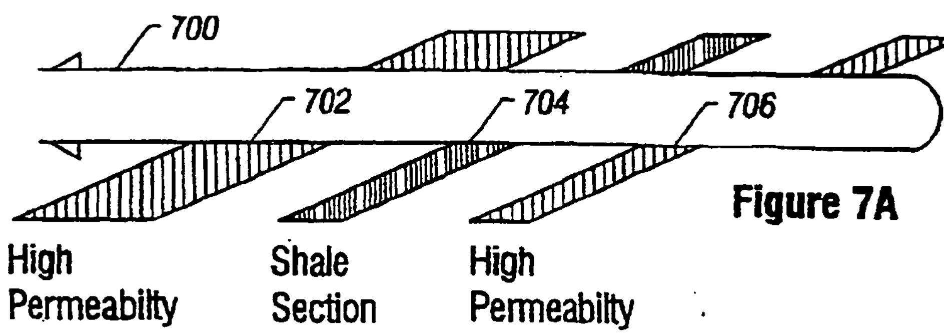


Figure 7A

The well has been drilled, logged and geophysical map has been created

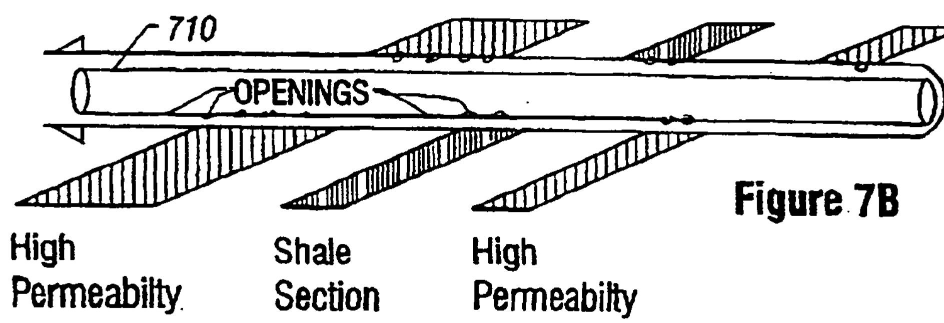


Figure 7B

Reservoir Inflow Control Device Is Run In Place

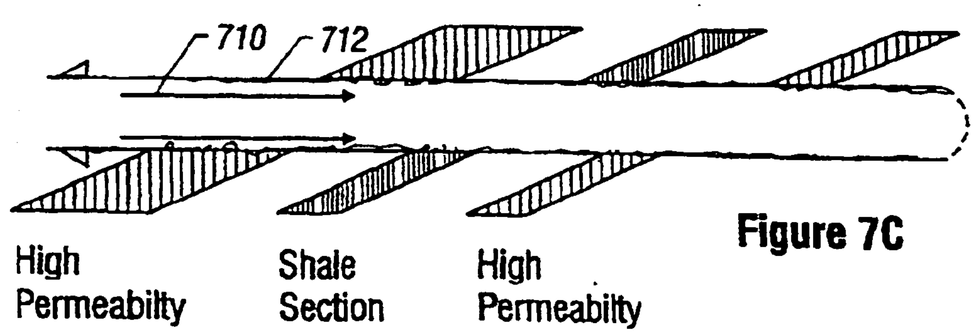


Figure 7C

Reservoir Inflow Control Device Is Installed
And Production Liner Can Be Run

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FLOW CONTROL APPARATUS AND METHOD

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates generally to methods of producing hydrocarbons from wellbores formed in subsurface formations and more particularly to apparatus and methods for regulating and/or equalizing production from different zones of a wellbore to optimize the production from the associated reservoirs or pay zones.

2. Background of the Art

To produce hydrocarbons from earth formations, wellbores are drilled into reservoirs or pay zones. Such wellbores are completed and perforated at one or more zones to recover hydrocarbons from the reservoirs. Horizontal wellbores are now frequently formed into a pay zone to increase production and to obtain on the aggregate higher quantities of the hydrocarbons from such reservoirs.

Sand screens of various designs and slotted liners are commonly placed between the formation and a tubing (production tubing) in the

wellbore, which transports formation fluid to the surface to prevent entry of sand and other solid particulates into the tubing. Screens of different sizes and configuration are commonly used as sand control devices. The prior art screens typically erode substantially over time. The present invention provides a screen which is less susceptible to erosion compared to prior art screens.

Excessive fluid flow rates from any production zone can cause, among other things, excessive pressure drop between the formation and the wellbore casing, relatively quick erosion of inflow devices, water or gas coning, caving, etc. Therefore, to avoid such problems, fluid flow from each production zone is controlled or regulated. Several flow control devices have been utilized for regulating or controlling production of formation fluids. One recent device passes the formation fluid through a spiral around a tubular to reduce the pressure drop before the fluid is allowed to enter the tubing. The spiral provides a tortuous path, which can be plugged at one or more places to adjust the fluid flow from the formation to the tubing. This device, although effective, must be set at the surface prior to its installation. United States Patent Application Serial No. 08/673,483 to Coon, filed on July 1, 1996, and assigned to the assignee of this application, discloses an electrically operable sliding sleeve for controlling fluid flow through a

tortuous path. This sliding sleeve may be operated from the surface. U.S. Application No. 08/673,483 is incorporated herein by reference. The present invention provides a flow control device that can be opened, closed or set at any intermediate flow rate from the surface. It also includes multiple fluid paths, each of which may be independently controlled to control the formation-fluid flow into the tubing.

In vertical wellbores, several zones are produced simultaneously. In horizontal wellbores, the wellbore may be perforated at several zones, but is typically produced from one zone at a time. This is because the prior art methods are not designed to equalize flow from the reservoir throughout the entire wellbore. Further, the prior art methods attempt to control pressure drops and not the fluid flows from each of the zones simultaneously.

The present invention provides methods for equalizing fluid flow from multiple producing zones in a horizontal wellbore. Each production zone may be independently controlled from the surface or downhole. This invention also provides an alternative system wherein fluid flow from various zones is set at the surface based on reservoir modeling and field simulations.

SUMMARY OF THE INVENTION

The present invention provides a fluid flow control device for controlling the formation-fluid flow rate through a production string. The device includes a generally tubular body for placement into the wellbore. The tubular body is lined with a sand screen and an outer shroud. The shroud reduces the amount of fluid that directly impacts the outer surface of the screen, thereby reducing the screen erosion and increasing the screen life. The fluid from the screen flows into one or more tortuous paths. Each tortuous path has an associated flow control device, which can be activated to independently open or close each tortuous path. Alternatively, flow from each path may be regulated to a desired rate.

Each flow control device further may include a control unit for controlling the output of the flow control device. The control unit may communicate with a surface control unit, which is preferably a computer-based system. The control unit performs two-way data and signal communication with the surface unit. The control unit can be programmed to control its associated device based on command signals from the surface unit or based on programs stored in the control unit. The communication may be via any suitable data communication link including a wireline,

acoustic and electromagnetic telemetry system. Each flow control device may be independently controlled without interrupting the fluid flow through the production string. The flow control devices may communicate with each other and control the fluid flow based on instructions programmed in their respective control units and/or based on command signals provided from the surface control unit.

In a preferred method, a plurality of spaced apart flow control device are deployed along the length of the horizontal wellbore. In one method of the invention, it is preferred to draw fluids from various zones in a manner that will deplete the reservoir uniformly along the entire length of the wellbore. To achieve uniform depletion, each flow control device is initially set at a rate determined from initial reservoir simulations or models. The depletion rate, water, oil and gas content, pressure, temperature and other desired parameters are determined over a time period. This data is utilized to update the initial reservoir model, which in turn is utilized to adjust the flow rate from one or more zones so as to equalize the flow rate from the reservoir.

In an alternative method, production zones are defined and flow setting for each zone is fixed at the surface prior to installation of the flow

control devices. Such a system is relatively inexpensive but would only partially equalize the production from the reservoir as it would be based on *a priori* reservoir knowledge.

The present invention provides a method of producing hydrocarbons from a reservoir having a deviated/substantially horizontal wellbore formed therein, said method, comprising: (a) placing a plurality of flow control devices in the wellbore, each flow control device set to produce formation fluid at an initial rate associated with each such flow control device; (b) determining at least one characteristic of the fluid produced through the wellbore; and (c) adjusting the flow rate through said flow control devices so as to equalize depletion of hydrocarbons from the reservoir over a time period.

Examples of the more important features of the invention have been summarized rather broadly in order that the detailed description thereof that follows may be better understood, and in order that the contributions to the art may be appreciated. There are, of course, additional features of the invention that will be described hereinafter and which will form the subject of the claims appended hereto.

BRIEF DESCRIPTION OF THE DRAWINGS

For detailed understanding of the present invention, reference should be made to the following detailed description of the preferred embodiment, taken in conjunction with the accompanying drawings, in which like elements have been given like numerals, and wherein:

FIG. 1 shows a horizontal wellbore having a plurality of spaced apart flow control devices for producing hydrocarbons from a reservoir according to one method of the present invention.

FIG. 2A shows a partial schematic view of a flow control device for use in the system shown in FIG. 1.

FIG. 2B shows a partial cut off view of a sand control section for use with the flow control device of FIG. 2A.

FIG. 3 shows control devices and certain sensors for use with the flow control device of FIG 2A.

FIG. 4 shows a hypothetical graph showing the flow rate from various

zones of a horizontal wellbore according to one method of the present invention.

FIG. 5 shows a relationship between the pressure differential and the flow rate associated with various production zones of a wellbore.

FIG. 6 shows a scenario relating to the effect of adjusting the flow rate from a production zone on production of hydrocarbons and water from such zone.

FIG. 7 shows an alternative method of equalizing production from a reservoir by a horizontal wellbore to the method of system of FIG. 1

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

FIG. 1 is a schematic illustrating a system 10 for producing hydrocarbons from a wellbore according to one method of the present invention. FIG. 1 shows a wellbore 14 having an upper casing 12 formed in an earth formation 11 according to any known method. A plurality of fluid flow devices or fluid flow devices 20a-n are placed spaced apart in the horizontal segment 14a of the wellbore 14. For the purposes of this

disclosure, a flow control device is generally designated by numeral **20**. The construction and operation of a novel flow control device for use as the flow control devices **20** are described below in reference to **FIGS 2A-B**. However, for the purpose of this invention, any suitable flow control device may also be used. The spacings between the flow control devices **20** are determined based on the characteristics of the reservoir **11**, as described in more detail later.

Each flow control device **20a-n** includes a flow valve and a control unit. The devices **20a-n** are respectively shown to contain flow regulation devices such as valves, valves **24a-n** and control units **26a-n**. For the purposes of this invention, a flow control device is generally designated by numeral **24** and a control unit is generally designated by numeral **26**. Also, for the purpose of this invention, flow control valves **24** shall mean to include any device that is utilized to control the flow of fluid from the reservoir **11** into the wellbore **14** and control units **26** shall mean to include any circuit or device that controls the flow valves **24**.

When the wellbore is in production phase, fluid **40** flows from the formation **11** into channels **22a** - **22n** at each flow control device, as shown by the arrow **22a'-22n'**. The flow rate through any flow control devices **20** will depend upon the setting of its associated flow control valve **24**. For the

purpose of illustration, the flow rates associated with the flow control devices **20a-20n** are respectively designated by Q_1-Q_n corresponding to production zones Z_1-Z_n of the formation **11**.

Still referring to **FIG. 1**, each flow control device **20a-20n** or zone Z_1-Z_n may have any number of devices and sensors for determining selected formation and wellbore parameters. Elements **30a-30n** respectively represent such devices and sensors corresponding to flow control devices **20a-20n** or zones Z_1-Z_n. Such devices and sensors are generally designated by numeral **30**. Devices and sensors **30** preferably include temperature sensors, pressure sensors, differential pressure sensors for providing the pressure drop between selected locations corresponding to the production zones Z_1-Z_n, flow rate devices, and devices for determining the constituents (oil, gas and water) of the formation fluid **40**. Packers **34** may be selectively placed in the wellbore **14** to prevent the passage of the fluids through the annulus **39** between adjacent sections.

The control units **26a-26n** control the operation of their associated flow control valves **24a-24n**. Each control unit **26** preferably includes programmable devices, such as microprocessors, memory devices and other circuits for controlling the operation of the flow control devices **20** and for communicating with other sensors and devices **30**. The control units **26**

also may be adapted to receive signals and data from the devices and sensors 30 and to process such information to determine the downhole conditions and parameters of interest. The control units 26 can be programmed to operate their corresponding flow control devices 20 based upon stored programs or commands provided from an external unit. They preferably have a two way communication with a surface control system 50. The surface control system 50 preferably is a computer-based system and is coupled to a display and monitor 52 and other peripherals, generally referred to by numeral 54, which may include a recorder, alarms, satellite communication units, etc.

Prior to drilling any wellbore, such as the wellbore 12, seismic surveys are made to map the subsurface formations, such as the formation 11. If other wellbores have been drilled in the same field, well data would exist for the field 11. All such information is preferably utilized to simulate the condition of the reservoir 11 surrounding the wellbore 14. The reservoir simulation or model is then utilized to determine the location of each flow control device 20 in the wellbore 14 and the initial flow rates Q_1-Q_n. The flow control devices 20a-20n are preferably set at the surface to produce formation fluids therethrough at such initial flow rates. The flow control devices 20a-20n are then installed at their selected locations in the wellbore

14 by any suitable method known in the art.

The production from each flow control device 20 achieves a certain initial equilibrium. The data from the devices 30a-30n is processed to determine the fluid constituents, pressure drops, and any other desired parameters. Based on the results of the computed parameters, the initial or starting reservoir model is updated. The updated model is then utilized to determine the desired flow rates for each of the zones Z_1-Z_n that will substantially equalize the production from the reservoir 11. The flow rate through each of the flow control devices 20a-20n is then independently adjusted so as to uniformly deplete the reservoir. For example, if a particular zone starts to produce water at more than a preset value, the flow control device associated with such zone is activated to reduce the production from such zone. The fluid production from any zone producing mostly water may be completely turned off. This method allows manipulating the production from the reservoir so as to retrieve the most amount of hydrocarbons from a given reservoir. Typically, the flow rate from each producing zone decreases over time. The system of the present invention makes it possible to independently and remotely adjust the flow of fluids from each of the producing zones, without shutting down production.

The control units **26a-26n** may communicate with each other and control the fluid flow through their associated flow control devices to optimize the production from the wellbore **14**. The instructions for controlling the flow may be programmed in downhole memory (not shown) associated with each such control unit or in the surface control unit **50**. Thus, the present invention provides a fluid flow control system **10**, wherein the flow rate associated with a number of producing zones Z_1-Z_n may be independently adjusted, without requiring physical intervention, such as a shifting device, or requiring the retrieval of the flow control device or requiring shutting down production.

The surface control unit **50** may be programmed to display on the display unit **52** any desired information, including the position of each flow control valve **24a-24n**, the flow rate from each of the producing zones Z_1-Z_n, oil/water content or oil and gas content, pressure and temperature of each of the producing zones Z_1-Z_n, and pressure drop across each flow control device **20a-20n**.

Still referring to FIG. 1, as noted above, the system **10** contains various sensors distributed along the wellbore **14**, which provide information about the flow rate, oil, water and gas content, pressure and temperature of each zone Z_1-Z_n. This information enables determination of the effect of

each production zone Z_1-Z_n on the reservoir **11** and provides early warnings about potential problems with the wellbore **14** and the reservoir **11**. The information is also utilized to determine when to perform remedial work, which may include cleaning operations and injection operations. The system **10** is utilized to determine the location and extent of the injection operations and also to monitor the injection operations. The system **10** can be operated from the surface or made autonomous, wherein the system obtains information about downhole parameters of interest, communicate information between the various devices, and takes the necessary actions based on programmed instructions provided to the downhole control units **26a-26n**. The system **10** may be designed wherein the downhole control units **16a-16n** communicate selected results to the surface, communicate results and data to the surface or operate valves **24a-24n** and **30a-30n** based on commands received from the surface unit **50**.

FIG. 2A shows a partial schematic view of a flow control device **200** for use in the system of **FIG. 1**. The device **200** has an outer sand control element **202** and an inner cylindrical member **204** together forming a fluid channel **206** therebetween. Formation fluid enters the channel **206** via the sand control element **202**. The channel **206** delivers the formation fluid **210** to one or more spiral tubings or conduits **214** or tortuous paths, which

reduce the pressure drop between the inlet and the outlet of the spiral tubings **214**. The fluid **210** leaving the tubings **214** is discharged into the production tubing **220** from where it is transported to the surface.

FIG. 2B shows a partial cut-off view of a sand control section **235** for use with the flow control device **200** of FIG. 2A. It includes an outer shroud **235** which has alternating protruded surfaces **240** and indented or receded surfaces **242**. The protruded surfaces **240** have sides **244** cut at an angle providing a vector design. This vector design inhibits the impact effect of the formation fluid on the shroud **235** and the screen **250**, which is disposed inside the shroud **235**.

FIG. 3 is a schematic illustration showing a control unit for controlling the flow through the flow control device **200** of FIG. 2. FIG. 3 shows four tubings **214** numbered 1-4 and helically placed around the tubular device **204** (FIG. 2A). The tubings 1-4 may be of different sizes. A flow control device at the output of each of the tubings 1-4 controls the fluid flow through its associated tubing. In the example of FIG. 3, valves **310a-310d** respectively control flow through tubings 1-4. A common flow control device (not shown) may be utilized to control the flow of fluid through the tubings 1-4. Flow meters and other sensors, such as temperature sensors,

pressure sensors etc. may be placed at any suitable location in the device 200. In FIG. 3, flow measuring devices 314a-314d are shown disposed at the tubing 1-4 outlets. The output from the tubings 1-4 is respectively shown by q_1-q_4. A suitably disposed control unit 330 controls the operation of the valves 310a-310d and receives information from the devices 314a-314d. The control unit 330 also processes information from the various suitably disposed devices and sensors 320 that preferably include: resistivity devices, devices to determine the constituents of the formation fluid, temperature sensors, pressure sensors and differential pressure sensors, and communicates such information to other devices, including the surface control unit 50 (FIG. 1) and other control units such as control units 26a-26n (FIG. 1).

FIGS. 4 and 5 illustrate examples of flow rates from multiple reservoir segments. In FIGS. 4 and 5, the flow rates Q_1-Q_n correspond to the zones Z_1-Z_n shown in FIG. 1. The actual flow rates are determined as described above. By manipulating the flow rates Q_1-Q_n, optimum flow rate profile for the reservoir can be obtained. The total reservoir flow rate Q shown along the vertical axis is the sum of the individual flow rates Q_1-Q_n. Here the fluid regulating device (such as 310a-310n, FIG 7) utilized to control the fluid discharge from the tortuous path operates at a fluid velocity where the fluid

flow from the formation is substantially insensitive to pressure changes in the formation near the flow control device and, thus, acts as a control valve for controlling the fluid discharge from the formation. This is shown by the position between dotted lines in FIG. 5, where Δp is the pressure drop.

FIG. 6 shows how adjusting the flow rate Q can reduce or eliminate production of unwanted fluids from the reservoir. It shows the potential impact of adjusting the flow rate on the production of constituents of the formation fluid. Q_o denotes the oil flow rate and Q_w denotes the water flow rate from a particular zone. As the formation fluid flow continues over time, the water production Q_w may start to increase at time T_1 and continue to increase as shown by the curved section 602. As the water production increases; the oil production decreases, as shown by the curved sections 604. The system of the present invention would adjust the flow rate, i.e., increase or decrease the production so as to reduce the water production. The example of FIG. 6 shows that decreasing the overall production Q from level 610 to 612 reduces the water production from level 608 to level 609 and stabilizes the oil production at level 620. Thus, in the present invention, the overall production from a reservoir is optimized by manipulating the production flows of the various production zones. The above described methods equally apply to production from multi-lateral wellbores.

FIG. 7A-7C show an alternative method of equalizing production from a horizontal wellbore. FIG. 7A shows a horizontal wellbore with zones 702, 704 and 706 having different or contrasting permeabilities. The desired production from each of the zones is determined according to the reservoir model available for the wellbore 700, as described above. To achieve equalized production from the various zones, a flow control device 710 in the form of a relatively thin liner is set in the welllbore 700. The liner 710 has openings corresponding to the areas that are selected to be produced in proportion to the desired flow rates from such areas. The openings are preferably set or made at the surface prior to installation of the liner 710 in the wellbore. To install the liner 710, an expander device (not shown) is pulled through the inside of the liner 710 to create contact between the formation 700 and the liner 710. A sand control liner 712 is then run in the wellbore to ensure borehole stability when the wellbore is brought to production. Thus, in one aspect, this method comprises: drilling and logging a wellbore; determining producing and isolated intervals of the wellbore; installing reservoir inflow control system; installing a production liner in the wellbore; installing a production tubing in the wellbore; and producing formation fluids.

While the foregoing disclosure is directed to the preferred embodiments of the invention, various modifications will be apparent to those skilled in the art. It is intended that all variations within the scope and spirit of the appended claims be embraced by the foregoing disclosure.

Claims:

1. A system for producing formation fluid through a production tubing in a wellbore formed in a formation comprising:

    (a) at least one fluid flow device disposed in the wellbore, each said at least one fluid flow device having a flow line reducing pressure between an inlet receiving such fluid and an outlet discharging said fluid into the production tubing;

    (b) A flow regulation device controlling the fluid discharge from each said flow line; and

    (c) A control unit for controlling the operation of the flow regulation device to control the fluid flow into the production tubing.

2. The system of claim 1 wherein the at least one fluid flow device includes a plurality of spaced apart fluid flow devices arranged serially in the wellbore.

3. The system of claim 2 wherein the control units control the flow of formation fluid through each fluid flow device.

4. The system of claim 3 wherein the control units control the flow upon receiving a command sign from a remote location.

5. The system of any preceding claim wherein the flow line is a tubing helically arranged around a tubular member, providing a tortuous path for the flow of formation fluid therethrough.

6. The system of any preceding claim wherein the flow line indicates a plurality of tortuous flow paths and the control device controls the flow of the formation fluid through said tortuous paths.

7. The system of any preceding claim wherein each control unit operates independently to substantially uniformly deplete the reservoir.

8. The system of any preceding claim further comprising a sensor in the well bore providing measurements for a downhole production parameter.

9. The system of claim 8 wherein the control unit operates the flow regulation device as a function of the downhole production parameter.

10. The system of claim 9 wherein the downhole production parameter is one of (a) temperature, (b) pressure,(c) flow flow rate, and (d) resistivity.

11. A sand control device for use in a wellbore comprising:

(a) a shroud having plurality of alternating protruded surfaces and receded surfaces with the protruded surfaces having irregular surface adapted to reduce the impact of the formation fluid on the shroud; and

(b) a screen disposed in the shroud for preventing the flow of certain particulates from passing the screen.

12. A method of equalizing production from a wellbore having a plurality of production zones comprising:

(a) Conveying an expandable liner into the wellbore, said expandable liner having flow paths adjacent each production zone for allowing the formation fluid to flow from the production zones into the wellbore; and

(b) expanding the liner within the well to place said liner in contact with the wellbore walls; and

(c) placing a sand control device adjacent each flow path in said liner.

13. A system for producing formation fluid through a production tubing in a wellbore formed in a formation substantially as hereinbefore described with reference to the accompanying drawings.

14. A sand control device for use in a wellbore substantially as hereinbefore described with reference to the accompanying drawings.

15. A method of equalizing production from a wellbore having a plurality of production zones substantially as hereinbefore described with reference to the accompanying drawings.

The Patent Office

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Application No:	GB 9809705.8	**Examiner:**	Richard Collins
Claims searched:	1-10+13	**Date of search:**	1 October 1998

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.P): E1F FLE, FLM, FLW, FJF.

Int Cl (Ed.6): E21B

Other: None

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
A	GB 2302114 A (Baker Hughes Incorporated) abstract.	-
A	GB 851096 A (Sun Oil Co.) Whole document.	-
A	US 5597042 A (Baker Hughes Incorporated) abstract.	-

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
		E	Patent document published on or after, but with priority date earlier than, the filing date of this application.
&	Member of the same patent family		